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FLAME-RETARDANT CLOTHING AND TEXTILE ITEMS FOR USE IN OXYGEN-ENRICHED ENVIRONMENTS OF DECOMPRESSION CHAMBERS

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Natick, Massachusetts

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ABSTRACT

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Small-scale laboratory tests by Ocean Systems, Inc., on the flame retardancy of materials in oxygen-enriched environments led to the selection of candidate materials offering a potential for use. Candidate materials were fabricated into end items and were subjected to a user evaluation to determine wearer acceptance. Full-scale flammability tests were performed on items made from materials selected for further study. Analyses of all test results led to the selection of Durette (modified Nomex) fabrics as offering the best compromise choice of materials for use in end-item constructions.

Clothing and textile items were manufactured and forwarded to selected Navy decompression-chamber sites, which are using them on a permanent basis. Information based upon a limited use has shown the items to be acceptable in terms of design, performance and durability. Static generation on Durette materials, reported by some activities, can be effectively controlled by the use of anti-stat softeners during the laundry cycle.

FLAME-RETARDANT CLOTHING AND TEXTILE ITEMS
FOR USE IN OXYGEN-ENRICHED ENVIRONMENTS
OF DECOMPRESSION CHAMBERS

INTRODUCTION

The Navy Clothing and Textile Research Unit (NCTRU) has developed clothing and textile items for use in the fire-hazardous, oxygen-enriched atmospheres of divers' decompression chambers. The U.S. Navy Experimental Diving Unit (NEDU) had requested that special fireproof clothing and fabrics be developed for use in decompression chambers, which themselves are used in the prevention or treatment of decompression sickness (commonly known as the "bends"). Divers have been more frequently exposed to hazardous, high-oxygen environments than in past years because of the development of the Man-in-the-Sea project, the Swimmer's Support System, and the Deep Salvage and Dive System. NEDU selected the following operational parameters or chamber atmospheric extremes, having the greatest fire hazard, for which protection must be provided (1).

(a) 21% oxygen at 200 feet of sea water (fsw)*
(b) 25% oxygen at 60 feet of sea water (fsw)
(c) Humidity in excess of 55%

The objective of NCTRU's program was to develop specifically requested clothing and textile items for the protection of divers and decompression-chamber personnel against fire and associated hazards of oxygen-enriched atmospheres of divers' decompression chambers. After testing several candidate fabrics, we chose Durette (modified Nomex) and developed the following: chamber items--mattress cover, blanket, pillowcase, sheets, face cloth, towel; clothing items--robe, jumper, trousers, undershirt, drawers, socks, handkerchief, and carryall bag. This report discusses: (a) the investigation, test and evaluation of selected candidate materials, and (b) the design, construction and prototype end-item development.

BACKGROUND

It is difficult for anyone actively engaged in diving operations to make valid evaluations of the flammability characteristics of materials under hyperbaric conditions. Standardized combustion tests, such as those specified and required by the Government, the Underwriters Laboratory, and the American Association of Testing and Materials (ASTM), are carried out in air at atmospheric pressure. These tests rarely represent the combustion phenomena that the same materials would exhibit in the high-oxygen (pressurized) environments of hyperbaric chambers. Numerous materials, which are termed "non-flammable or fireproof," under standard normal atmospheric conditions, burn readily in compressed-air environments.

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*Feet of sea water (fsw). Every 33 fsw exert a pressure of 14.7 psi or 1 atm. At 200 fsw, the total pressure being 7.06 atm. abs. or 103.7 psia; for 60 fsw, the total pressure is 2.82 atm. abs. or 41.4 psia.

Since April 1966, the Office of Naval Research and the Naval Ship Systems Command, prompted by (a) the renewed interest in the exploration of the oceans and of the natural resources which they afford, (b) the need for the Navy and other organizations to send divers safely to ever increasing depths and to return them safely, and (c) the fatal fire experienced by the Navy in February 1965 (2), have conducted a research program on combustion safety in diving atmospheres. The study was initiated under contract N00014-66-C-0149 (1966) between the Office of Naval Research and the Linde Division of the Union Carbide Corporation. It continued under contract N00014-70-C-0169 (1971) with Ocean Systems, Inc., an affiliate of the Union Carbide Corporation and the Singer Company. This study was not involved solely in the fire-resistant testing of materials since the contractual requirements also concerned investigatory efforts into such areas as: environmental parameters affecting combustion in hyperbaric environments; potential sources of ignition; high-expansion-foam fire-extinguishing tests; and combustion tests on prototype clothing in decompression chambers. The Linde Research Laboratory also surveyed and reported on the vast amount of literature that had been published on flame-retardant materials, tests, and problems of fire hazards in confined spaces (3).

Most of the information on flame-retardant testing of materials and end items in oxygen-enriched atmospheres that is contained in this report is from information reported by Ocean Systems, Inc., in its summary reports on Combustion Safety in Diving Atmospheres (3, 4, 5).

DEVELOPMENT OF A SCALE OF FIRE RESISTANCE FOR SCREENING MATERIALS

Initially, in its testing of materials for flame retardancy in oxygen-enriched atmospheres, Ocean Systems reported the ignition temperatures and burning rates of materials under a wide variety of gas compositions and pressures; however, this system of reporting proved to be impractical when a quick comparison of materials was desired. Subsequently, Ocean Systems developed a scale of fire resistance in compressed-air and oxygen-enriched environments in which the sample was tested in air at atmospheric pressure, in compressed air, and in oxygen-nitrogen mixtures containing increasing amounts of oxygen at a total pressure of 1 atmosphere absolute. The tested material is rated in one of ten classifications that are comprised in the Scale of Fire Resistance (see Table I).

At first glance, the mixing of classes for compressed air (Classes 3 and 4) with classes at atmospheric pressure and with varying percentages of oxygen may seem illogical. Ocean Systems reported that there were two reasons for this arrangement. First, compressed air represents the most hazardous atmosphere (from a fire safety point of view) that is normally used in a decompression chamber. It is of vital importance that materials be tested under these conditions to assess their safety in diving operations. Second, at a pressure of 1 atmosphere absolute, many materials ignite more easily and burn faster with every percentage point as the percentage of oxygen is increased from 21% (the percentage in air) to 25% oxygen. Experimentally, it was difficult to ensure that the gas composition was exactly 22%, 25%, etc. The portion of the scale between 21% and 25% oxygen was therefore accommodated in an entirely different way--namely, by the insertion of two compressed-air steps.

Table I. Scale of Fire Resistance

Class 0. Burns readily in air at atmospheric pressure. (Cotton is an example of material in this class.)

Class 1. Has an appreciably higher ignition temperature and/or burns at an appreciably lower rate in air at 1 atm abs pressure than cotton cloth or paper. (An example of a Class 1 material is wool.)

Class 2. Non-flammable or self-extinguishing in air at 1 atm abs pressure.

Class 3. Self-extinguishing or burns slowly in air at a pressure of 100 feet of sea water (4.03 atm abs).

Class 4. Self-extinguishing or burns slowly in air at a pressure of 200 fsw (7.06 atm abs).

Class 5. Self-extinguishing or burns slowly in a mixture of 25% oxygen and 75% nitrogen at a pressure of 1 atm abs.

Class 6. Self-extinguishing or burns slowly in a mixture of 30% oxygen and 70% nitrogen at a pressure of 1 atm abs.

Class 7. Self-extinguishing or burns slowly in a mixture of 40% oxygen and 60% nitrogen at a pressure of 1 atm abs.

Class 8. Self-extinguishing or burns slowly in a mixture of 50% oxygen and 50% nitrogen at a pressure of 1 atm abs.

Class 9. Non-flammable in 100% oxygen at a pressure of 1 atm abs.

For most materials, the fire resistance decreased in the order 21% oxygen at 1 atmosphere absolute, 100 fsw air, 200 fsw air, and 25% oxygen at 1 atmosphere absolute. Unfortunately, there were a few cases in which materials that self-extinguished or burned slowly in 25% oxygen (Class 5) were found to burn in air at either 100 or 200 fsw pressure. Materials are classified in the lowest class in which they fit.

APPARATUS USED IN SCREENING OF FLAME-RETARDANT MATERIALS

The apparatus used by Ocean Systems in their evaluations in essence consisted of a stainless-steel cylinder, 6 inches inside diameter by 20 inches in length. A 2-inch window served as a view port. A series of pins on rods held the sample in position. Ignition was accomplished by a chromel resistance wire located at the lower end of the sample. Chromel-alumel thermocouples placed at intervals along the sample measured the burning rates.

In testing, the sample and sample holder were mounted in the pressure vessel. Samples were tested in the vertical position (most severe) in determining their class in the scale of fire resistance. The pressure vessel was evacuated and filled with the desired gas mixture at the required pressure.

A more detailed description of the small test pressure chamber and test procedure is contained in the First Summary Report on Combustion Safety in Diving Atmospheres (3).

OBSERVATIONS ON MATERIAL EVALUATIONS

Burning rates vary not only with gas composition, pressure, and the angle of testing, but also with sample size, weight, shape, weave, humidity, etc. Burning rates are relative, but are useful for comparison purposes.

It should be noted that the parameter of 25% oxygen at 60 fsw pressure (one of the operational requirements established by NEDU) was not a specific class in Ocean Systems' scale of fire resistance. The scale was developed before this particular operational parameter was established. The other parameter of air at 200 fsw was covered by Class 4. The classification of flame-retardant materials into specific categories in the scale provides the most complete source of valuable information in the selection of candidate flame-retardant fabrics for use in decompression chambers.

In addition to information on flame-retardant materials developed by Linde Research Laboratory and Ocean Systems, Inc., NCTRU looked at other sources of pertinent information (6, 7) that provide excellent information on the behavior of flame-retardant materials in varied oxygen-enriched atmospheres.

Because of the many variables that affect flame retardancy, it is improbable that any test method will be developed to measure the flame retardancy of all fabrics under all conditions. The best that can be expected of any test method is the comparative rating of test materials under the particular conditions of test. Obviously, the best method for laboratory screening is that which most closely simulates the conditions of actual use. On the other hand, evaluation of candidate materials can best be accomplished by full-scale testing of clothing and materials under actual conditions of use.

CANDIDATE MATERIALS OFFERING A POTENTIAL FOR USE

During the course of Linde Research Laboratory and Ocean Systems' contracts, over 100 flame-retardant materials were screened and classified into a specific category in the scale of fire resistance.

Materials listed in Table II were selected by Ocean Systems as candidate fabrics offering a potential for use in the fabrication of suitable prototype flame-retardant clothing and textile items to meet the project's objectives. A listing of all materials tested and classified (fabrics, electrical insulations, elastomers, paints, plastics, etc.) is contained in the Compendium of Hyperbaric Fire-Safety Research (8).

Table II. Candidate Material Classification on the Scale of Fire Resistance

Fabric	Class
Beta Fiberglas	9
Asbestos/Fiberglas/Nomex	9
Teflon-coated Beta Fiberglas	9
Teflon	8
Polybenzimidazole (PBI)	7
Durette Gold	6
Fypro	4

We do not intend to convey the impression that only those fabrics listed in Table II possessed the required flame retardancy to be considered as candidates for use in decompression chambers. Several other fabrics that were tested had equal or higher classifications in the fire-resistance scale. They were not considered to be candidates because of one or more of the following reasons: (a) they were experimental and, if available, were available only in very limited quantities and constructions; (b) they did not possess the physical properties in fabric form (strength, abrasion resistance, and durability) that are required of textile items; (c) their performance properties had not been fully explored; (d) there was no assurance that the materials could be reproduced in quantity; and (e) they were too costly in comparison with other commercially available fabrics that were more suitable.

Beta Fiberglas (Class 9)

This is an Owens-Corning product which can be made into fabrics by weaving or knitting. Beta Fiberglas is different from other types of glass fibers in that beta fibers are extremely fine (less than 4 microns in diameter). In making beta cloth for use in h h-oxygen-enriched environments, it is necessary to use a special silicone-lubricant finish (less than 1% by weight). No evidence of combustion of the lubricant was apparent in flammability testing. In fact, Beta Fiberglas is non-flammable even in 100% oxygen at 1 atmosphere.

Moreover, beta fabrics have dimensional stability and are available at reasonable costs. Some possible disadvantages of beta fabrics in clothing applications include: minor skin irritation may be reported by some individuals; a relatively low order of surface abrasion; complete lack of moisture regain which affects wearer comfort; and heavier weight compared with most other fabrics of equivalent thickness.

Asbestos/Fiberglas/Nomex Composite (Class 9)

This Asbestos (79%)/Fiberglas (14%)/Nomex (7%) composite, an experimental fabric developed by Uniroyal for the National Aeronautics and Space Administration (NASA), is designed to have flame resistance in high-oxygen tensions and to provide a thermal barrier in space applications. Unfortunately, the material is relatively stiff and heavy, and a suitable finish must be used to prevent linting and scuffing. Another disadvantage is its low order of abrasion resistance that seemingly precludes its use in clothing. It may, however, be useful in static situations.

Teflon-Coated Beta Fiberglas (Class 9)

Two Teflon-coated Beta Fiberglas fabrics were tested. A Teflon coating was applied to beta fabrics to improve surface abrasion; however, the tearing strength was lowered because of yarn immobilization. A new fabric developed for NASA (sometimes called Super-Beta) was made from beta yarns which were Teflon coated prior to weaving. This process resulted in a fabric of improved surface abrasion resistance and good porosity. It still was a relatively heavy fabric with no moisture-regain properties. It was also limited in its availability.

Teflon (Class 8)

Teflon is a fluorinated polymer of DuPont (tetrafluorethylene, or TFE), available in fabric form in brown and white colorations. The brown Teflon has approximately 7% carbonaceous residue formed in the polymerization process. The white Teflon has been "purified" to remove this residue and, as a result, it is more expensive. Both the brown and the white Teflon are similar in physical properties and in flame retardancy; however, the white Teflon is reported by Ocean Systems to be superior in 100% oxygen atmospheres. The relative heaviness, low coefficient of friction (slipperiness), and the lack of moisture regain may be disadvantages--particularly in clothing applications.

Polybenzimidazole (PBI) (Class 7)

PBI is a flame-retardant fiber developed jointly by the Celanese Corporation and the U.S. Air Force. PBI fabrics have a naturally brown color. They have physical and flame-retardancy properties considered suitable for most applications. One important advantage of PBI that is not found in other inherent flame-retardant fibers is a moisture-regain equivalent to that of cotton. This fact seemingly makes a properly constructed fabric suitable for clothing and textile end items. PBI does have its drawbacks--it is not commercially available and it is very expensive. If there develops a sufficient demand by Government or industry to warrant large-scale production, fiber costs will probably be substantially reduced.

Durette Gold (X-400 series) (Class 6)

Durette is the name applied to a Nomex aramid that has been modified by a proprietary process of Monsanto. (All Durette materials discussed in this report are of the Durette Gold 400 series.) Durette is nonflammable in air and in modest oxygen-enriched environments. The physical properties of properly constructed Durette fabrics are considered to be satisfactory. At the time of flammability testing, Durette was available in limited fabric constructions at moderately high costs. Since this time, the cost has been substantially lowered and new fabrics have become available. Its low moisture regain may prove to be somewhat of a disadvantage in clothing.

Fypro (Class 4)

Fypro, which is produced by Travis Mills, is the name applied to a Nomex aramid that has been modified by a proprietary process different from that of Monsanto. Fypro, which is deep purplish-brown in its natural processing color, is nonflammable in air and in minimal oxygen-enriched atmospheres. Fypro, like Durette, was limited in available fabric forms at the time of flammability testing. However, it has since become available in a variety of constructions.

NOTE: Class 4 materials were included in the test of candidate fabrics because they might be useful if properly covered and protected by fabrics having a higher order of flame retardancy.

OTHER IMPORTANT FACTORS IN CANDIDATE MATERIAL SELECTION

Until now, most of the information contained in this report concerned the results of testing of materials to determine their fire resistance in oxygen-enriched atmospheres, since the question of fire resistance should be considered first. There are also other factors of major importance that must be considered before any final selection of materials can be made. These are toxicity of combustion products, wearer comfort and acceptance of materials in end items, and material and end-item performance under conditions of use.

Toxicity of Combustion Products

A brief study of the major products of combustion resulting from the candidate materials when burned in oxygen atmospheres was performed by Ocean Systems using gas chromotographic and mass spectrometric analyses. Test results are contained in their third summary report on combustion safety (5). Major contaminants were carbon monoxide and carbon dioxide. Other contaminants, mainly fluorocarbons and aromatic derivatives of benzene were found in small concentrations in all samples. Ocean Systems reported:

> . . .although the presence of highly toxic substances in small quantities has not been ruled out, in view of the difficulty of burning these materials, we feel that products of complete combustion do not represent a serious hazard. (5)

NOTE: NCTRU believes that toxicity and smoke generation of flame-retardant materials is an area that should be explored in detail—particularly the possible effects of combinations of small quantities of toxic gases in pressurized environments without ready escape.

Wearer Comfort and Acceptance

The importance of wearer comfort and acceptance in the development of clothing and textile items for use in decompression chambers is obvious. No matter how fire protective an item of apparel may be, if it does not provide a satisfactory degree of comfort and acceptance, it will not be worn. (This is particularly true for divers undergoing routine decompression requiring lengthy stays in decompression chambers.)

End-Item Performance

Textile items and the materials from which these items are made must also have acceptable levels of performance during routine wash-wear maintenance. Frequent replacement of relatively expensive clothing and textile items would not be acceptable to the activities funding the procurement or to the users of the items.

It was evident that a service evaluation by the potential users of flame-retardant clothing fabricated from various candidate materials would provide the best source of information as to both wearer acceptance and performance of the items in use.

Accordingly, this Unit procured limited quantities of candidate fabrics for in-house fabrication of end items. Selection of the candidate materials at the time was based on the availability of those fabrics having constructions considered suitable for textile applications. Those few textile items made from candidate materials that could be obtained elsewhere (other than in-house fabricated) were procured and included with the other prototypes to be user evaluated.

DEVELOPMENT OF PROTOTYPE ITEMS FOR USER EVALUATION

Design, pattern development, cutting and fabrication of the prototype items were performed by NCTRU designers using sizing and/or dimensional guides furnished by NEDU.

Nomex and Durette sewing threads were used in the fabrication. Fypro thread was not made and other threads (Glass, Teflon) did not perform satisfactorily in preliminary sewing tests. At the time, Durette thread (460 denier, 2 ply) was available in very limited quantities. Because the "Durettizing" process results in some reduction in the original physical properties of the material, it was not known whether this thread (when it became available) would be suitable. In answer to our request, the U.S. Army Natick Laboratories (NLABS) performed an evaluation of Durette Gold fabric and sewing thread (9). NLABS concluded, on the basis of limited data obtained, that Durette sewing thread would perform satisfactorily in production sewing and would provide adequate seam strength for the intended purpose.

In the manufacture of prototype items, the only identification used was a letter code developed by NCTRU. This was done to avoid preliminary judgment by the users if the materials were made known in advance.

Table III contains information on the materials used, their source, and the prototype items that were developed. Also contained in the table is information concerning those items that were obtained from commercial sources and those that were obtained from cooperating activities.

RESULTS OF LIMITED USER EVALUATION OF PROTOTYPE ITEMS

Prototype items were submitted to NEDU for user evaluation. Subsequently, we learned (10) that the items had undergone a very limited comfort and wear evaluation, and the results had been favorable. The design/style, fit and comfort to the users had been well accepted. The limited wash cycles to which the garments had been subjected had shown no detrimental effect on their use. A more comprehensive comfort and wearer evaluation was later performed on a series of dives conducted in the NEDU chambers. These tests showed (11) that the items that were identified as those fabricated from PBI and Durette were the most acceptable to the wearers. The other items were not favorably accepted because of one or more of the following criticisms: cold and clammy, slippery, heavy, uncomfortable because it does not pick up body moisture, objectionable dark color, stiff.

FULL-SCALE COMBUSTION TESTS ON PROTOTYPE CLOTHING

The classification of flame-retardant materials on the scale of fire resistance provided the means for the selection of candidate fabrics. However, the classifications were determined by testing in the various oxygen-enriched environments of a small-scale laboratory pressure cylinder. As stated earlier in this report, because of the many variables that affect the combustion of materials, laboratory test results may not indicate the combustion phenomena exhibited by materials in end-item forms in a full-size operational decompression chamber. Therefore, full-scale tests were performed

Table III. Prototype Items Developed for User Evaluation

Fabric	Source	Item
Fypro (Fypro #5006) 6.0 oz/sq yd, twill, 80 x 72	Travis Mills	Jumpers, trousers, robes (fabricated in-house)
Durette (Monsanto X-400) 5.5 oz/sq yd, twill, 90 x 68 and Durette (X-400) 3.3 oz/sq yd, pajama check, 90 x 70	Monsanto	Jumpers, trousers robes, mattress covers, pillow cases (fabricated in-house)
Teflon-coated beta yarn - fabric Super-Beta, 7.0 oz/sq yd	Owens-Corning	Jumpers, trousers, robes, mattress covers, pillow cases (fabricated in-house)
Teflon brown 8.4 oz/sq yd, plain, 76 x 70	Stern and Stern Textiles	Jumpers, trousers, robes, mattress covers, pillow cases (fabricated in-house)
Teflon white (knitted)	Allen-A	Knitted T-shirts and jockey shorts (procured under contract)
PBI (knitted)	Wright-Patterson Air Force Base	Knitted long-sleeve undershirts and ankle-length drawers*
Asbestos/Nomex/glass 14.0 oz/sq yd, plain 24 x 20	Uniroyal	Carryall bags (sized to accommodate the clothing items) (fabricated in-house)
Nomex, light and heavy weight (knitted)	Allen-A	Long-sleeve undershirt and ankle-length drawers (procured commercially)**

*The only items available from WPAFB.

**Nomex items added as evaluation control of commercial flame-retardant items (Class 3 in Scale of Fire Resistance).

by Ocean Systems on prototype clothing in an operational chamber (12). Tests were performed on jumper and trouser clothing sets and on undershirt and drawer combinations. A set consisting of a cotton/polyester sweatshirt and cotton jeans served as the control. Also tested were knitted Nomex undershirts and drawers in various weights and constructions. These represented commercially available flame-retardant items.

Test Environment

Two test environments were selected that were considered to represent the most fire-hazardous conditions normally encountered in diving operations. One environment, compressed air at 165 fsw (88.13 psia - 5.99 atm. abs.), is the normal maximum air depth used in the treatment of decompression sickness. The other environment of 25% oxygen/75% nitrogen at 60 fsw (41.40 psia - 2.82 atm. abs.) was selected since a 25% oxygen level may be attained during oxygen breathing with a mask in which the air is enriched by exhaled oxygen despite frequent air flushing of the chamber.

Test Apparatus and Equipment

Test Chamber. Combustion tests were conducted in a full-size, U.S. Navy single-lock decompression chamber having a volume of approximately 250 cubic feet and a working pressure of 225 fsw (114.82 psia - 7.81 atm. abs.). The chamber was plumbed with oxygen, nitrogen and helium lines and could be evacuated for in-situ gas mixtures. The chamber was also instrumented for temperature and pressure recordings. A 16-mm color-motion-picture camera was mounted externally to the chamber view-port to record the end-item performances under test.

Mannequin. To simulate the human form, a hollow-metal mannequin (with movable arm and leg joints) was dressed in the garments to be tested. A hook and bracket in the top of the head allowed the mannequin to be suspended in the chamber. In testing, the clothed mannequin was suspended from the chamber ceiling with the legs straight out to ensure adequate air circulation.

Ignition Source. To simulate a sudden flaming heat source, as might be experienced under actual conditions, a movable, electric-heating coil (linked to a revolving thread and rod), powered by an air motor with external valving, was used. External valving allowed the heat source to be moved at controlled speeds. Two specimens of 1-foot-square cotton-print cloth soaked in methanol and draped over the heating coil served as the flaming heat source. In this manner the flammability of the clothing could be evaluated after it had been in contact with the flame for a short time. If a person were engulfed by flame and unable to move away from the fire, he would be a casualty regardless of the type of clothing he was wearing.

Test Procedure

Ocean Systems followed this procedure in conducting the full-scale combustion tests.

a. Photograph and weigh set of clothing to be tested.

b. Photograph dressed mannequin in chamber.

c. Pressurize chamber to desired environment.

d. Start temperature pressure recorders and motion picture camera.

e. Switch on heating coil (located approximately 10 inches in front of dressed mannequin at a height to impact mannequin in the front lower chest area).

f. After the first appearance of flame on the soaked cotton cloth, wait 5 seconds (full flaming).

g. Move flaming heat source to mannequin (approximate rate of 2 in/sec).

h. Keep flaming source in contact with clothed mannequin for 10 seconds.

i. Move flaming source away from mannequin.

j. After observing burning behavior of garments, clear chamber of smoke and record post-test data on movie film.

k. Photograph clothed mannequin.

l. Weigh and photograph garment remains.

Discussion of Test Results

We considered that only a percentage of weight loss greater than 2% was significant in evaluating the degree of flammability. It should be remembered that contact with the flaming heat source occurred in the lower chest area of the upper half of the garment assembly. If the material were relatively flame-retardant, the bottom half of the assembly was not ignited since flaming proceeded upward. On the more flammable materials, indirect ignition of the bottom half of the garments occurred. The test garments ranked in the same order in both environments, with the most hazardous condition being compressed air at 165 fsw. Because of the few garments that were available for test, the results did not have statistical validity. Therefore, in the evaluation of the test results, garment weight losses were carefully considered along with a thorough examination of the movie film, pre-test and post-test photographs. Consideration of these facts led Ocean Systems to conclude: "Teflon, Teflon-coated Beta, Durette and PBI were all in the same flammability order of magnitude based on weight losses" (all less than 3%). However, Teflon and Teflon-coated Beta sustained little or no combustion after attempted ignition, whereas Durette and PBI burned weakly and smoldered for short periods.

Fypro exhibited a continual weak burning and smoldering after ignition, with a weight loss of approximately 6%.

Nomex, which when burned, produced a large amount of black smoke, suffered an approximate 50% weight loss. Cotton and cotton/polyester ignited easily, burned intensely and were completely consumed within minutes.

Prototype decompression-chamber test results are summarized and categorized in Table IV. Detailed information on the combustion tests of prototype clothing is contained in reference (12).

Table IV. Classification of Prototype Decompression-Chamber Clothing (Full-Scale Tests)

Acceptable (for safe chamber operation)	Unacceptable
Best	Fair
Teflon-coated Beta-Fiberglas	Nomex
Brown Teflon	
White Teflon	Poor/Dangerous
Better	Cotton
	Cotton/Polyester
Durette	
PBI	
Good	
Fypro	

SELECTION OF DURETTE AS MOST SUITABLE MATERIAL

After analysis of all information and with consideration of such factors as cost and availability, both NCTRU and Ocean Systems concluded that Durette Gold materials offered the best compromise choice for the fabrication of flame-retardant textiles that would meet the objectives of the program. Subsequently, the Supervisor of Diving (SUPDIVE), Naval Ship Systems Command, funded this Unit for the contracting of Durette clothing and textile items in sufficient quantities to initially outfit about 50 Navy decompression chambers.

When Durette materials were tested in the early stages of our program, only a few fabrics were available and these at high costs. During the intervening time, additional Durette materials became available in a variety of constructions and weights and at much lower prices. Durette materials, like most other textile fabrics, are price-volume sensitive. Therefore, in the selection of materials for the program funded by SUPDIVE and in the interest of economy in obtaining the most for the least, consideration was given to the procurement of single-type fabrics that could be used in the fabrication of a variety of end items. Table V contains the brief description of the selected Durette materials that were used.

Table V. Physical Properties of Selected Durette Gold Materials

Monsanto Style No.	Construction	Weight oz/sq yd	Thread Count (min.)	Strength/Grab (lbs-min)
400-2	Spun yarn (SY) $\frac{2}{1}$ twill	5.2 ± 0.2	88 x 65	130 x 95
400-6	SY plain weave	4.4 ± 0.2	46 x 42	110 x 82
400-11	Needlepunch batting	10.9 ± 0.5	—	130 (burst)
400-17	SY plain weave	3.3 ± 0.2	82 x 70	80 x 70
400-13	SY duck, plain weave	10.9 ± 0.5	45 x 31	300 x 200
400-27	1 x 1 rib knit, $\frac{22}{1}$ S twist	6.0 ± 0.2	28 x 30 (W x C)	—
Sewing Thread	400-600 denier, 2 ply	—	—	2.8 (single strand, lb.)

DESIGN AND DEVELOPMENT OF DURETTE ITEMS

NCTRU developed prototype end items and their corresponding patterns to serve as reference standards for the design, construction and fabrication of Durette items under contract. Clothing items were fabricated in medium and large sizes and in the basic styles requested by SUPDIVE. Carryall bags were made that could hold one complete clothing set and articles of personal hygiene. Durette sewing threads were required to be used in the manufacture of all items. However, a few items other than clothing were sewn with another type of approved flame-retardant thread because of the unavailability of Durette sewing thread at the time of manufacture. General information on the materials, design and construction of the items follows (also see Figure 1).

1. The robe, made from Durette 400-2 cloth, consisted of a one-piece back with left and right fronts. Belt loops were sewn in the side seam at the waist. A one-piece set-in sleeve and a two-piece shawl collar and facing were used. The undercollar and undercollar interlining were quilted before being joined to the topcollar. A patch pocket was located waist high on the right front. A tie belt, made from Durette 400-2 cloth, was supplied with the robe.

2. The jumper, made from Durette 400-2 cloth, consisted of a stand-up collar with a front opening at the neck. The undercollar was quilted to an undercollar interlining before being joined to the topcollar. A two-ply, front-opening, extension facing was attached on the inside of the front opening. The collar was set between the jumper top and the jumper facing, with a button and button tab positioned on either side of the front opening at the neck. The sleeves were set in with a Nomex elastic tape inserted into each sleeve-bottom hem.

3. The trousers, made from Durette 400-2 cloth, had a fly front, two hip patch pockets, and a Nomex elastic tape inserted into each leg-bottom hem. A waistband was positioned on the outside of the trouser top forming a tunnel through which a tie tape, made of Durette 400-2, was inserted. The tie tape was secured by a bartack at the center-back of the waistband.

4. The handkerchief, made from Durette 400-17 cloth, was a 14-inch by 14-inch square with a 1/16- to 1/32-inch finished hem on all four sides.

5. The pillowcase, made from Durette 400-6 cloth, was rectangular. Its finished measurements were 19-1/2 inches by 30-1/2 inches. The open end had a finished 2-inch hem.

6. The mattress cover, made from Durette 400-6 cloth, was a box type with an open flap with tie cords. Its finished measurements were 77 inches by 28 inches by 4-1/2 inches.

7. The sheet, made from Durette 400-6 cloth, had a 2-inch finished hem at the top and a 3/8-inch finished hem at the bottom. Its finished measurements were 108 inches by 53-1/2 inches.

Figure 1. Front View of Decompression-Chamber Clothing and Textile Items—Jumper, Trousers, Robe, Carryall Bag and Towel.

8. The carryall bag, made of Durette 400-13 cloth, was of a rectangular shape with a slide fastener securing the top of the bag. A 2-ply flap completely covered the slide-fastener closure. Two carrying straps, one on each side, were attached around the outside of the bag. The finished measurements of the bag were 18 inches by 7 inches by 7-1/2 inches.

9. The blanket, made from Durette 400-11 needlepunched batting, was bound on all four sides by a 1-3/4-inch bias-cut binding, made from Durette 400-6 cloth. Its finished measurements were 90 inches by 53-1/2 inches.

10. The socks, made from 100% aramid, were of a crew style with a reinforced heel and toe. The finished weight of a dozen socks after being "Duretted" was 36 ounces for size 11 to 11-1/2.

11. The undershirt, made from Durette 400-27 cloth, was of a long-sleeve pullover style with a crew collar and knitted cuffs, also made from Durette 400-27 cloth.

12. The underdrawers, made from Durette 400-27 cloth, were ankle length with a drawstring waistband and knitted leg cuffs, also made from Durette 400-27 cloth.

13. The face cloth, which had a terry-loop construction, was made from a Durette fabric with an equivalent cotton count of 16 singles, 10 singles, and 6 singles. The face cloth measured 12 inches by 12 inches and weighed 1.30 pounds per dozen.

14. The towel, made from a Durette fabric, had the same yarn sizes and terry-loop construction as the face cloth. It measured 22 inches by 44 inches and weighed 8.25 pounds per dozen.

STATIC BUILDUP ON DURETTE ITEMS

The Durette clothing and textile items fabricated under contract were assembled into sets and forwarded to Navy decompression chamber sites selected by SUPDIVE.

After the Durette items were in use for some time, it was reported in an article (13) that certain commands had expressed a concern that items of this type (Durette) tend to become charged with static electricity when handled, and therefore could become a hazard in decompression-chamber use. SUPDIVE in the same article responded that extensive tests had been performed on representative samples and that static-electric energy levels created by the handling or rubbing of these materials are of extremely low magnitude and cannot cause combustion under the conditions intended for use. It was also reported in the article that commercially available anti-stat softeners would prevent static buildup.

This Unit, in a limited in-house study, verified and reported on the static buildup of Durette materials. This study also determined that several anti-stat softeners, including the Type-II laundry-rinse additive, Federal Stock No. 7930-965-9831, when applied as directed, provided an effective means of preventing static buildup on Durette materials (14).

Although the items have not had an extended evaluation that would provide desired information as to overall performance and wearer acceptance, limited information received to date has shown: (a) acceptability in design/style and durability; and, (b) need for other clothing sizes in addition to medium and large.

NCTRU believes that, after the Durette items have been in use for an extended period of time, information may be developed that will indicate areas requiring additional investigation.

CONCLUSIONS

It is apparent that inexpensive, off-the-shelf items that satisfy the safety standard required of clothing and textile items for use in the high-oxygen tensions of hyperbaric chambers are not available. Specialized fabrics are necessary, but they are limited in availability and relatively high in cost, and they limit wearer comfort and performance.

Based upon analyses of all test results, primarily those of large-scale flammability testing and limited user evaluations, we concluded that Durette fabrics at this time offer the best compromise choice of materials for use in the fabrication of flame-retardant clothing and textiles that meet the objectives of this program on flame-retardant materials.

Spurred by Government legislation concerning flammable materials, industry has engaged in extensive research efforts to develop new and better flame-retardant fibers and fabrics. It is entirely possible that in the future some of these materials will prove to be acceptable for use in decompression chambers.

ACKNOWLEDGEMENT

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